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Letter to the Editor

Hemodynamic consequences of restraints in the prone position in excited delirium syndrome

Dear Editor,

I read with interest the paper of Savaser et al. where several references were related to sudden and unexpected deaths of subjects restrained in the prone position for excited delirium.[1] Using transthoracic echocardiography, they measured hemodynamic parameters in 5 different positions. From the supine position to the prone maximal restraint (hogtie) position with 100 pounds (45.36 kg) of “weight force” applied to “the center of the back”, they showed a gradual decrease in the inferior vena cava diameter (IVC) and in the stroke volume (SV) of 19% and 17% respectively. In their discussion, they stated that their “observations do not support the hypothesis that sudden cardiovascular collapse occurs as a result of decreased venous return secondary to chest compression”. Considering the limitations of their study protocol and their results, I wonder if their statement can be applied to all cases of fatal excited delirium syndrome (ExDS).

Continuous chest compression may be innocuous, as in certain types of massage, or may result in cardiorespiratory arrest while leaving intact corpses as shown by Burke and Hare in 1828.[2] In fatal ExDS, multiple police officers are directly involved in a violent struggle with confused and hyperactive individuals described as having “a superhuman strength”[3] and the exact amount of weight applied to the subject's back is usually not mentioned in their report.[4–6] Using early reenactment, O'Halloran emphasized that first responders, in a stressful situation, may not be aware of the magnitude of the pressure applied on the chest when he reported an unexpected cardiac arrest in “a prone restraint position with a 250-pound (113.4 kg) attendant” “on the subject's back”.[7]

Savaser et al. referred to 2 articles describing 5 cases of sudden cardiac arrest following the application, with 1 or more than 1 knee, of an undefined amount of weight force on the subjects' back.[4,5] In their study protocol, the 45.36 kg of “weight force” was applied over a large surface area covering most of the back and the load velocity was not mentioned. The relationship between the force, the load velocity, the pressure and the surface area during chest compression has been studied by automotive engineers[8] and during cardiopulmonary resuscitation (CPR).[9,10] Compared to a peak force of 125 $\pm$ 18 kg applied over a large surface area of the chest, a peak force of 51 $\pm$ 20 kg applied by manual compression increased the pressure applied to the chest by 680% (203 $\pm$ 20 mmHg versus 1381 $\pm$ 432 mmHg) and resulted in a right atrial peak pressure of 83 $\pm$ 40 mmHg.[10] Transesophageal echocardiography has shown that manual chest compression during CPR results in a reduction of the left ventricular chamber[11] and that pressure on the spine during surgery in the prone position may “markedly” obstruct the right ventricular outflow tract in certain circumstances.[12] Invasive monitoring and end-tidal CO_2 have shown that the hemodynamical principles supporting chest compression during CPR are probably the same whether the individual is in the prone position or in the supine position.[13] Considering the sternal force–displacement relationship during CPR[14] and the fact that the normal central venous pressure (3–6 mmHg) increases by less than 4 mmHg during a 10-min exercise,[15] a 45.36 kg of “weight force”, rapidly and continuously applied with 1 knee to “the center of the back” of individuals in ExDS, should affect the venous return significantly. By reducing the central blood volume by 50%, the chest compression could result in a vasovagal response because transient central hypovolemia is known to induce bradycardia and sudden decrease in peripheral resistance.[16,17]

Under the heading “Limitations”, the authors did not mention if the 20 $\times$ 20 cm cutout in the wooden board for echocardiographic evaluation might have prevented compression of heart chambers and IVC. They mentioned that they “did not replicate all potential conditions in the field”, namely “physical exertion” and “psychological stress” explaining that “it is difficult to postulate a mechanism whereby these factors would affect our results as most of these factors would in all likelihood increase cardiac output”. Intense exercise implies a hypermetabolic state where the heart rate is close to its maximal value and the minute ventilation may be over 80 L/min.[18,19] In these circumstances, left ventricular filling “is enhanced” “by greater negative intrathoracic pressures” stressing the fact that cardiopulmonary adaptations are tightly coupled.[19] Restraining in the prone position, on a hard surface, an hyperactive individual will impede free expansion of the chest and the abdomen during inspiration, may interfere with cardiopulmonary adaptations by increasing the intraabdominal pressure and could further decrease the venous return.[20] The heart rate, already increased, may not be able to compensate for the decreased SV shown by the authors. In their study, a SD of 1.5 in the prone position implies that the cardiac output (CO) was as low as 2.8 L/min in some volunteers, a 44% reduction from the mean value in the supine position. Considering a maximal oxygen delivery and a maximal oxygen consumption of 4528 ml/min and 3600 ml/min respectively during intense exercise,[18] any decrease of more than 20% in the CO would lower the maximal oxygen delivery under the maximal oxygen consumption. Considering the prevalence of coronary heart disease and left ventricular hypertrophy in fatal ExDS,[6,21] a sudden decrease in myocardial oxygen delivery would be detrimental. A tight hogtie position could also reduce the venous return directly and indirectly by different mechanisms. By creating a lumbar hyperlordosis[22] and by reducing the surface area over

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which the body weight is lying, the pressure in the abdominal and thoracic cavities should increase the pressure on the IVC, especially in an obese individual. Considering that a Valsalva maneuver during a static exercise such as weight lifting may lead to syncope by drastically reducing the venous return,[23] the same clinical event could also occur when a psychotic and paranoid individual is forcefully struggling against tight restraints.

As the majority of individuals restrained in the prone position for ExDS do not die,[21] research should focus on the lower values observed in any study on fatal ExDS. In Savaser et al. study, it would have been interesting to know if there was a relationship between the lower CO values observed in their results and the higher body mass index of the volunteers (range of 23.6–35.3 kg/m^2) because the prone position and obesity are 2 predisposing factors of the abdominal compartment syndrome[20] and of sudden deaths of individuals restrained for ExDS.[21]

The few cases of fatal ExDS reported in the non-prone position should not rule out the prone position as a contributing or precipitating factor in fatal ExDS. In Hall et al. study, only the final resting position ("position of the subject once physical control had been achieved") was documented by police officers and "the various positions achieved during the struggle for the individual who died" were "not retrospectively" evaluated.[24] Hall et al. also mentioned that "they did not systematically record whether any weight force was applied at any time on the subject's back or shoulders, although there is little doubt that it occurred for some of our subjects."[24] The negative hemodynamic consequences resulting from the compression of the abdominal cavity in the prone position have been known for decades in anesthesiology.[25] In the supine position, tight restraints compressing the abdomen may also have the same consequences by increasing the intraabdominal pressure.[20] In these circumstances, relying on normal blood pressure values may be deceptive because systemic vascular resistance increases in parallel with decrease in CO.[26]

A recent article on treatment options in ExDS was suggesting the lateral position once the subject was restrained.[27] Considering that ExDS is a medical emergency[27] in individuals who may have poor cardiovascular reserve,[6,21] that none of the individuals restrained in the lateral position died in Stratton et al. study[21] and that the left lateral position facilitates the venous return,[28] developing restraint techniques that would not impede abdominal and chest expansion during inspiration in the lateral position should be considered.

In summary, cardiorespiratory adaptations to physical exertion is an important variable that can influence the clinical outcome of individuals in ExDS restrained in the prone position with continuous chest compression. By the nature of its design, the study by Savarer et al. could not address that factor appropriately. Therefore, the results of their study are not applicable to all cases of fatal ExDS.

Conflict of interest

None declared.

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